International Arctic Systems for Observing the Atmosphere (IASOA)

Aethalometer Measurements of Equivalent Black Carbon in the Arctic observatories as part of IASOA - Taking the Steps Forward

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Outline:

1) Definition of black carbon and what are the techniques?

2) What are we measuring with Aethalometer?

3) What are the issues related to these measurements?

4) How accurate these measurements should be to satisfy the modeling community?

5) What are the next steps in moving forward?
- 7 Arctic sites as part of IASOA
- Data Portals, data format, various corrections
- recommendations for corrections

What is Black Carbon?

- Carbonaceous particulate matter
  - a high fraction of which is sp^2-bonded carbon
- Consists of aggregates of spherules
  - Individually, from <10 to (typically) 50 nm in diameter
- Refractory
- Insoluble in water
- Strongly absorbs light across all visible wavelengths
  - when freshly emitted, has a mass absorption efficiency of at least 5 $m^2\ g^{-1}$ at the mid-visible wavelength of 550 nm

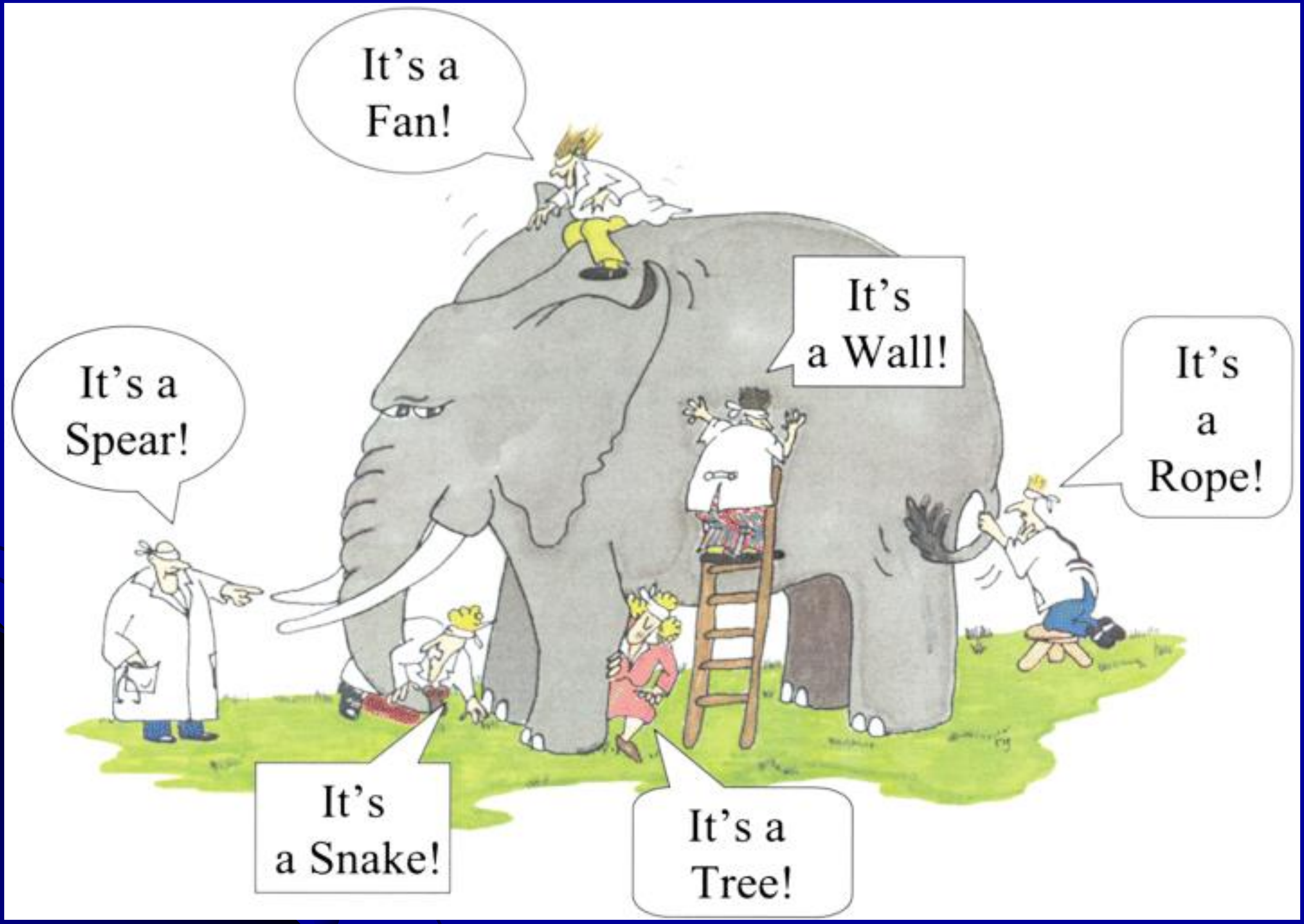
Petzold et al., 2013

Petzold et al., *Atmos. Chem. Phys. Discuss*., 13, 9485-9517, doi:10.5194/acpd-13-9485-2013, 2013.

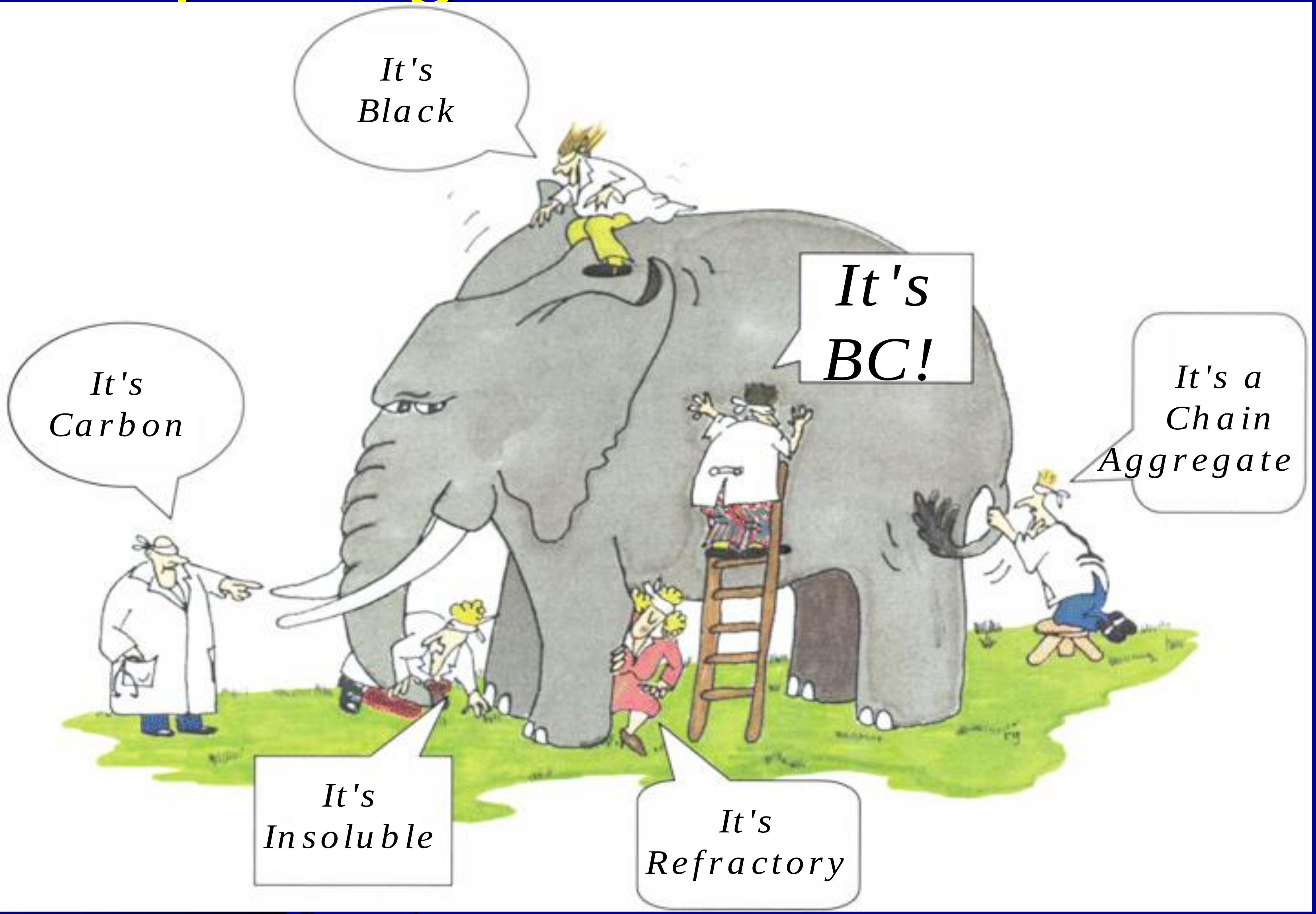
“BC” Measurement Methods

- **Light Absorption Coefficient (σ_{ap})**
  - **Derived from optical methods, e.g.,**
    - **Filter-based (aethalometer, PSAP, MAAP, COSMOS)**
    - **Suspended particles (e.g., photo-acoustic, extinction minus scattering)**
  - **Equivalent Black Carbon (EBC) mass**
    - **derived from σ_{ap} using a mass absorption efficiency α_{ap} (MAE)**
    - **the MAE used to calculate EBC must be specified**
  - **BC Properties: absorption**
- **Elemental Carbon (EC)**
  - **Derived from measurement of CO_2 evolved from thermal or thermo-optical methods**
    - **e.g., IMPROVE, TOT_900 EC or EUSAAR protocols**
  - **BC Properties: composition, refractory, absorption**
- **Refractory Black Carbon (rBC)**
  - **Derived from laser incandescence methods**
  - **BC Properties: composition, refractory, absorption**

Blind Men and the Elephant



Interpreting“BC” Measurements



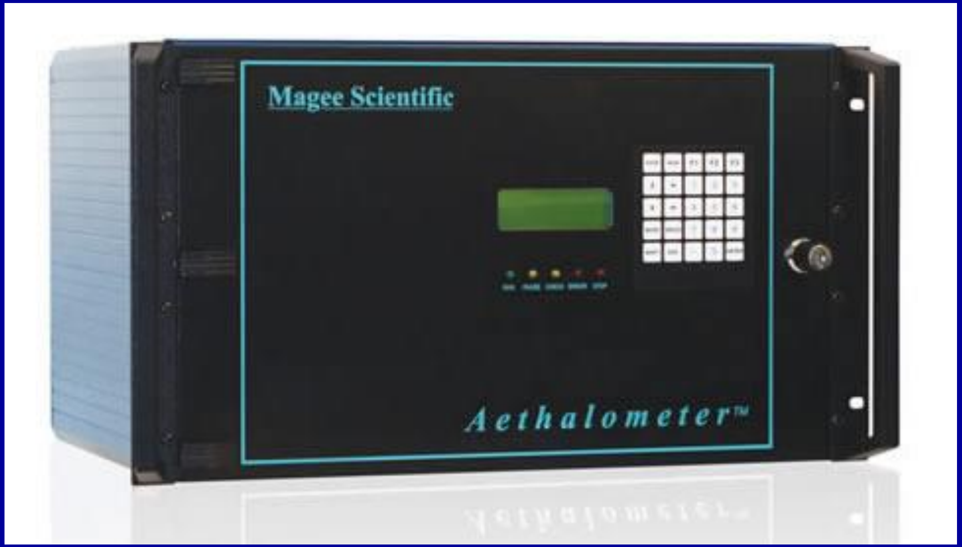
J. Ogren 6/11/2013

Recommended Terminology

- **No current method combines all five essential characteristics of BC**
- **Consequently, no current method can justifiably claim to provide a quantitative measurement of BC**
- **Recommendations**
  - **Use "BC" as a qualitative term referring to any of the quantitative methods**
  - **the source/method of "BC" observations should be identified by using the respective terms EBC, EC, or rBC as shown previously**

Petzold et al., 2013, ACPD

Aethalometer - Principle of Measurements of Equivalent Black Carbon (EBC)



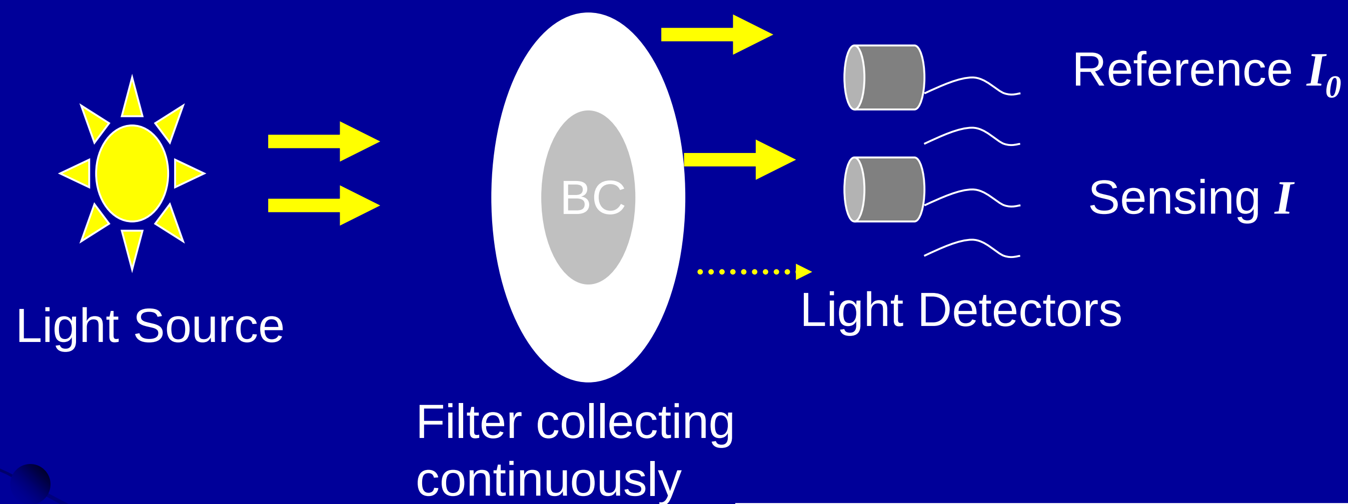
AE31-7 λ

UV 350 nm
Blue 450 nm
Green 571 nm
Yellow 590 nm
Red 660 nm
IR-1 880 nm
IR-2 950 nm

Light absorption inferred measurement

Aethalometer – ***Continuous*** optical analysis

Hansen, Rosen and Novakov (1984)



$$ATN = 100 * \ln(I_0 / I)$$

$$\mathbf{EBC} = \frac{\sigma_{ap}}{\alpha_{ap}} = \frac{100}{\alpha_{ap}} \cdot \frac{A}{Q} \cdot \frac{\Delta ATN}{\Delta t}$$

λ=wavelength

α_{ap}=Mass absorption Efficiency (MAE)

1) What are we measuring with Aethalometer?

Equivalent Black Carbon –the equivalent mass concentration of black carbon that produces the same attenuation as measured by the aethalometer

Different response to particles by combustion sources

- Fossil fuel (black)
- wood combustion (wild fires) brown carbon or
- organics that are darker in colour (Humic Like Substances)
- dust

Dependence of Absorbance by EBC

- wavelength
- aerosol ageing, thus composition and size of particle
- morphology of particle (e.g., small monomeric clusters or fractals or agglomerated fractals)

2) Challenges with the Aethalometer measurements?

Enhancement in the absorption of deposited particles

i) due to fibrous filter matrix

ii) as accumulation of aerosol increases –
leads to "shadowing effect"– response of aethalometer decreases as loading increases

iii) Scattering of transparent aerosol embedded in the filter
-This can reduce the shadowing effect.

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i) Enhancement in absorption due to fibrous Quartz filter matrix – multi-reflections

****Higher Mass Absorption Efficiency (MAE) is used instead of 8-10 m^2g^{-1}.**

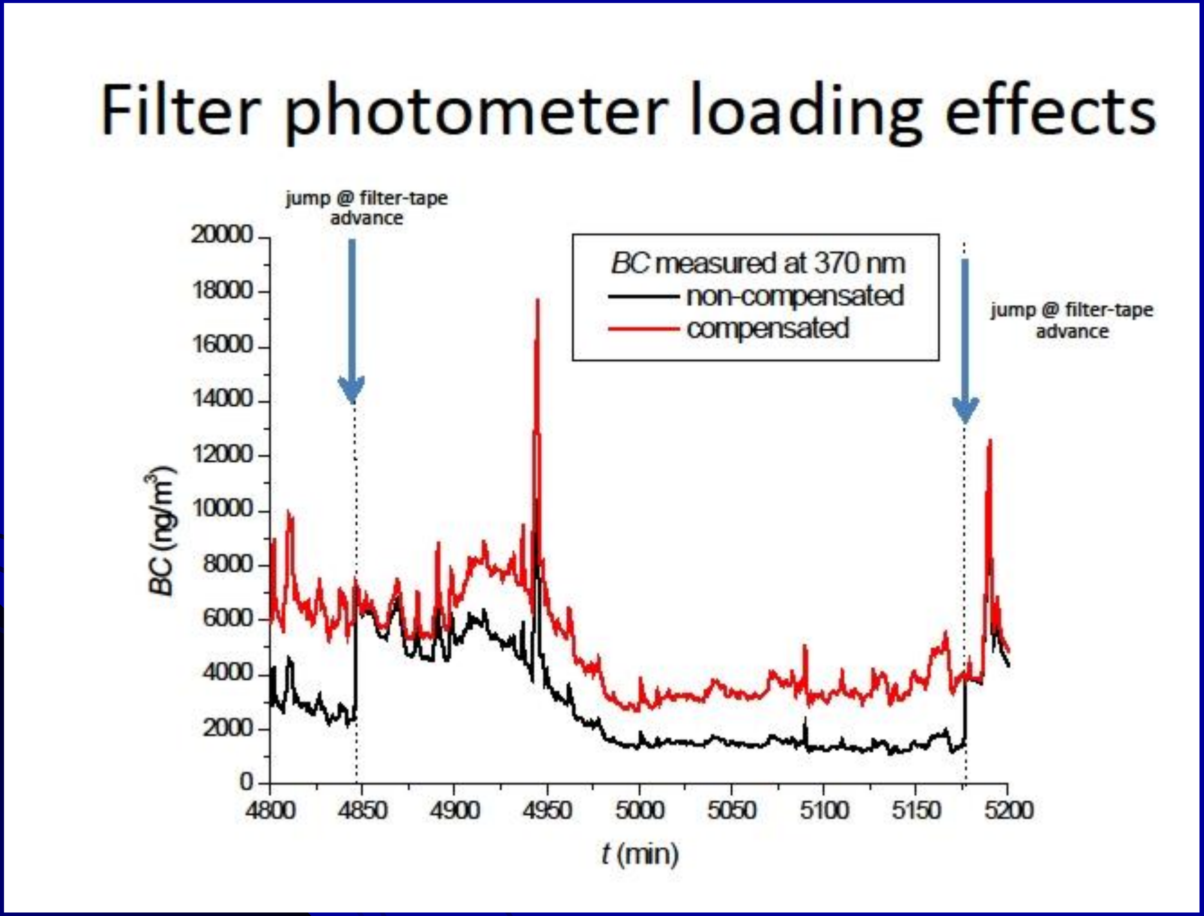
-Different models use different MAE

- **Old AE6 - incandescent lamp with broadband peaking near IR; *αap* or MAE= 19 m^2 g^{-1}**
- **AE16- advanced tape one wavelength 880 nm alpha or αap = 16 m^2 g^{-1}**
- **AE31 – 7 wavelength**

  αap = 14625 / λ

Lamp λ (nm)	αap (m²/g)
UV 370	39.5
Blue 470	31.1
Green 520	28.1
Yellow 590	24.8
Red 660	22.2
IR-1 880	16.6
IR-2 950	15.4

ii) Loading effects as aerosols accumulate (shadowing) –seen as filter tape advances to a fresh spot



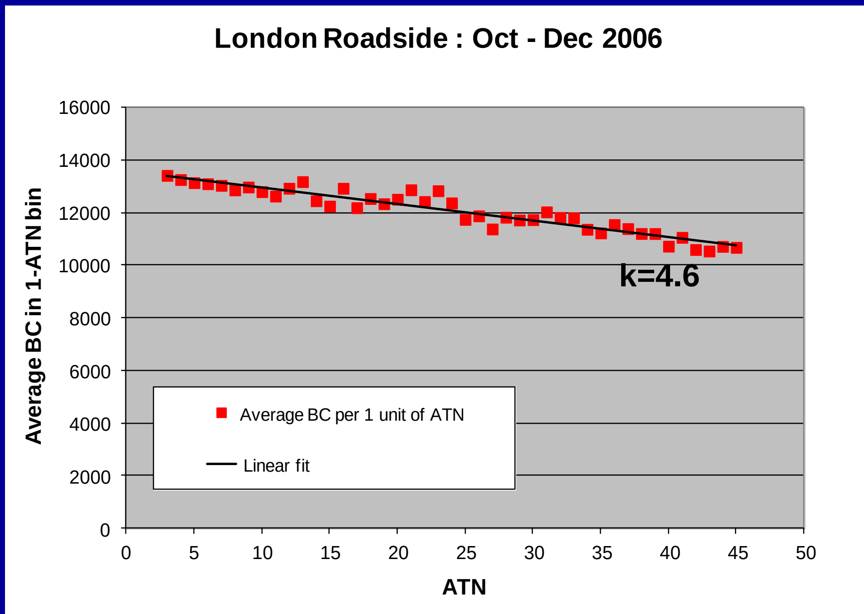
The relationship of ATN / BC becomes non-linear

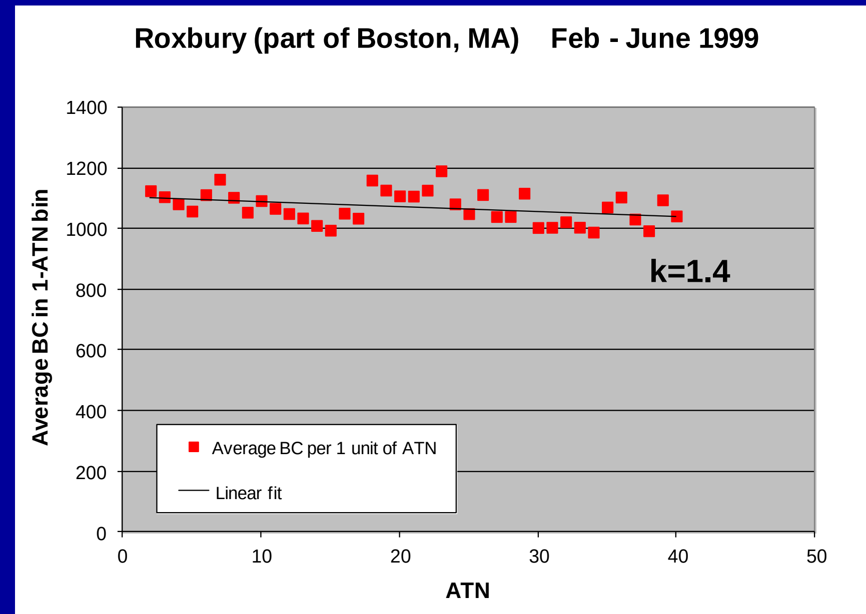
Courtesy of Tony Hansen

Loading effects in ambient data

Fresh emission influence vs aged particles

Avg. BC in 1- ATN bin





ATN

Courtesy: Tony Hansen

Correction is smaller for aged than fresh particles

Slope k=ΔBC/ΔATN is variable

-Location and season

-composition internal vs external mixing

-aerosol ageing

iii) Aerosol loading/Scattering Effects- Various Correction schemes

Results : Aerosol type, size and morphology thus Site Specific

1) Weingartner et al., 2003; Absorption of light by soot particles: determination of the absorption Coefficients by means of aethalometers, *Aerosol Science*, 34, 1445-1463
2) Arnott et al., 2005; Towards Aerosol Light Absorption Measurements with a 7-w aethalometer: Evaluation with Photoacoustic Instrument and 3-w Nephelometer, *Aer. Sci. & Tech., 39*,17-29
3) Virkkula et al., 2007; A simple procedure for correcting leading effects of Aethalometer Data, *JAWMA*, 57:10, 1214-1222
4) Schmidt et al., 2006, Spectral light absorption by ambient aerosols influenced by biomass burning in the Armazon basin. I: Comparison and field calibration of absorption measurement techniques, *Atmos. Chem. Phys*., 6, 3443-3462.
5) Collaud Coen et al., 2010; Minimizing light absorption measurement artifacts of the Aethalometer: evaluation of five correction algorithms, *Atmos. Meas. Tech*. , 3, 457-474.

Reference methods=Photoacoustic, extinction –scattering and MAAP

Highlights from these papers:

-Enhancement by 2.1 for uncoated soot and 3.6 by coated soot (1)

-AE overpredicts EBC at the start of filter change and underpredicts as filter gets dirtier (2) i.e., response of aethalometer decreases with aerosol loading

-AE responds to non-absorbing aerosols

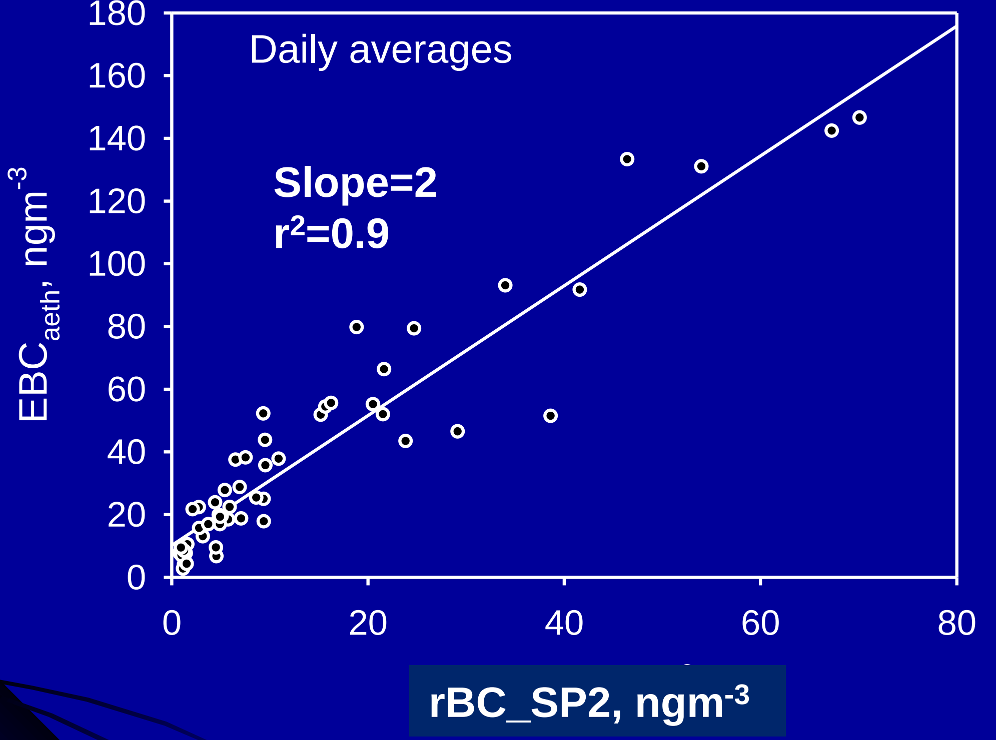
-AE correction factor is seasonal ; clean site filter change only causes 3% increase (3)

3. Comparisons of uncorrected aethalometer measurements with the other techniques

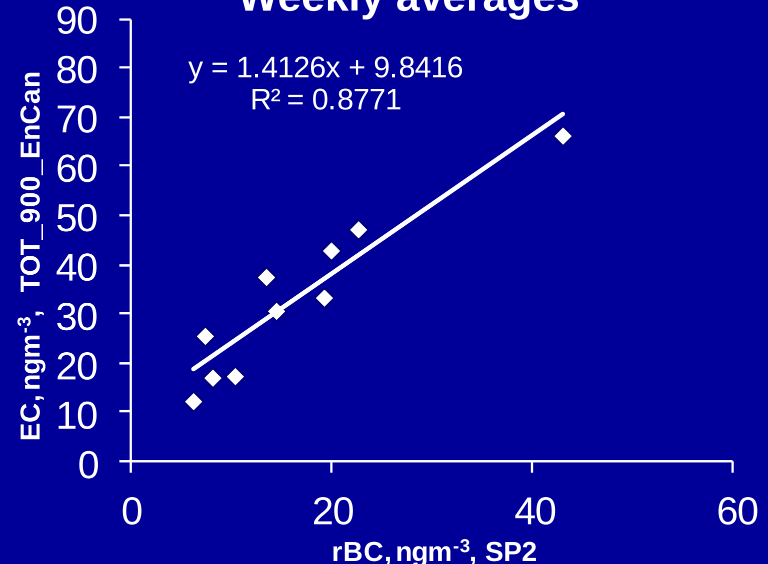
Technique		Ratio AE to technique	Locations	Reference
Thermal	EC/OC	0.5 to 2 1 to 2	Remote, Rural, urban Remote, Urban to rural	European sites; Liousse et al., 1996; Canadian sites; Sharma et al., 2002;2004
Multiple Angle Absorption Photometer (630nm)	absorption	2.4 to 3.6 1.4-1.6	Rural to urban Europe Leipzig, Germany	Collaud Coen et al., 2010 Eusaar/GAW2005 Müller et al., 2011
Photoacoustic (PAS)	absorption	---	---	Schmidt et al., 2006
Single Particle Soot Photometer (SP2)	refractory black carbon	1.5-2.5	Alert Spring Alert Summer	NOAA annual meeting

Some method comparisons at Alert

SP2 vs aethalometer



SP2 vs TOT_900_EnCan
Weekly averages



4. Steps forward - Arctic Stations conducting Aethalometer Measurements

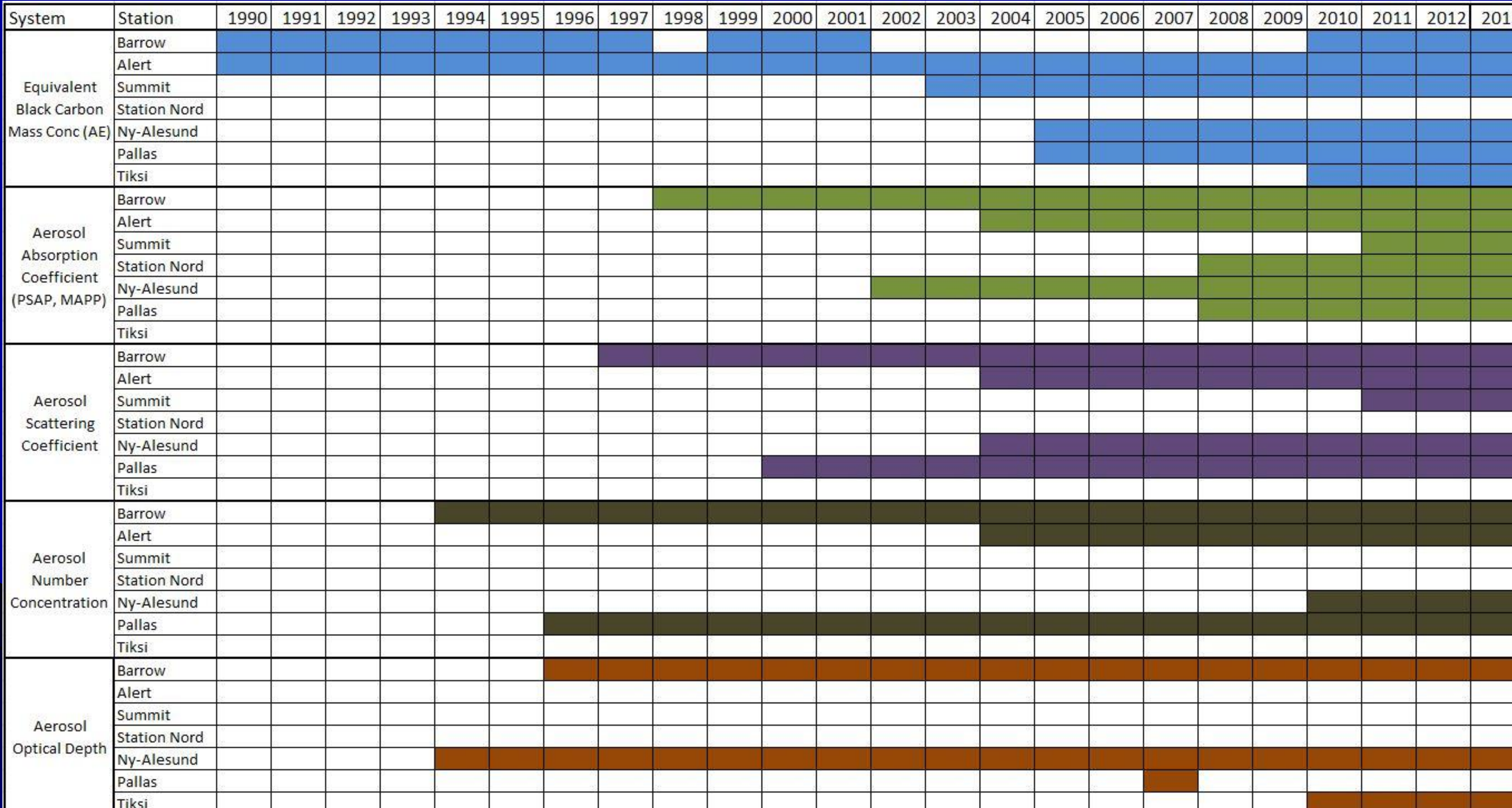
Different AE models

Remote locations

-long range Transport of air-masses
-aerosol type Internally mixed
-SSA > 0.96

What would be the enhancement in EBC??

Aethalometer and other measurements at 7 Arctic stations



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Data Submission to data portals: Need consistency

1) http://ebas.nilu.no - data available as light absorption $(Mm)^{-1}$

Alert	**Aethalometer**
Alert	**PSAP**
Summit	**PSAP**
Pallas	**MAAP**
Ny Ålesund (Zeppelin)	**Aethalometer**
Zeppelin	**PSAP**
Barrow	**PSAP**

2) -ftp.cmdl.noaa.gov/aerosol/brw/archive/1976-1997/

-ftp.cmdl.noaa.gov/aerosol/brw/archive/bc/

-ftp://ftp.etl.noaa.gov/psd3 - data are raw data files as per instrument as EBC mass (ngm^{-3}).

Barrow
Tiksi
Summit

Recommendations for application of correction to Aethalometer data:

1. Data should be submitted to the WMO World Data Center for Aerosols in Level-0 format

See http://www.gaw-wdca.org/SubmitData/AdvancedDataReporting/Level0/FilterAbsorptionPhotometerlevel0/MageeInstrumentslevel0/tabid/10528/Default.aspx

Flagged with local contamination, instrument malfunction.

2. Document the level of quality control:
   - -exposed area spot size correction applied compared to what is in the firmware
   - -flow-meter calibrations
   - -identification of local contamination sector from measurements (with wind or visual)
   - -settings for transmittance when spot size is changed.

3. Application of suitable correction factor Collaud Coen et al., 2010 method to all level-0 data to derive the best light absorption coefficient.

$$R_{new,} = \left(\frac{1}{m.(1-\omega_0)+1}\right).\frac{ATN_n}{50\%}+1$$

$$\sigma_{ap} = \frac{b_{ATN}}{(C_{ref}+C_{scat}).R_{new}} = \frac{A.\Delta ATN}{Q.\Delta t.C_{ref}.R_{new}}$$

Where C_{ref} = comparison of aethalometer and MAAP at Pallas site

α_{new}=0 no scattering data , C_{scat} =0, m=0.74 and

ω_0= climatological value from Delene & Ogren 2002 + other sites that have simultaneous measurements to derive ω_0

σap is defined for λ=532 nm. May be problem for instruments with 880 nm.

4. Comparison of weekly σ_{ap} from step 3 to EC (thermal technique) = α_{ap}

Hourly EBC = corrected σ_{ap}/ α_{ap}

5. Comparison to other techniques such as PSAP, MAAP and PAS for light absorption and Single Particle Soot Photometer and COSMOS for EBC.

6. Now we can start comparisons among sites and climatological influences for the trends (annual vs seasonal vs monthly values)

7. Look at Influence of brown carbon (biomass burning) in 7λ aethalometer – wood combustion in shorter wavelength then the fossil fuel

8. Need resources to do these analyses – need a PI dedicated for this.

Thank you for your attention!